

High efficiency transmission masks for EUV interference lithography

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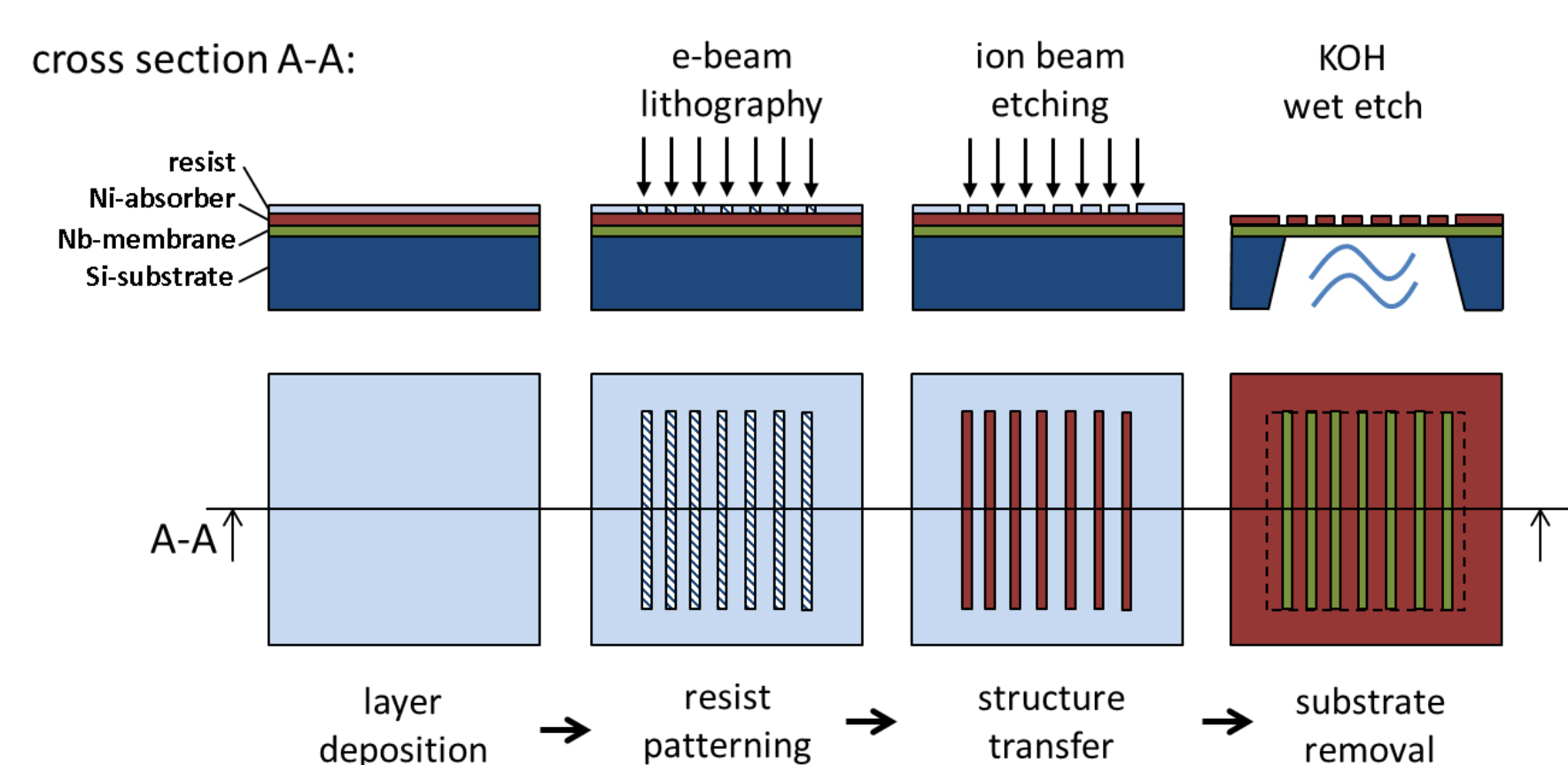
Abstract

Lithography with an extreme ultraviolet radiation (EUV) is currently the main candidate for next-generation optical lithography [1]. The structuring with EUV light pushes the diffraction resolution limit into sub-10 nm range due to the short wavelength (typically between 10 nm and 15 nm). However, number of technical challenges, such as availability of high power laboratory EUV sources, lifetime of optical components, mask manufacturing and defect control, slow the wide spread implementation of the technique. For interference lithography with EUV radiation one of the main challenges is a manufacturing of low-defect high-efficiency transmission gratings. Due to a very strong absorption of EUV radiation in a matter only a very thin (< 300 nm) free-standing membrane of selected materials can be used for a transmission part of the grating. Standard membrane technology utilizes silicon nitride membranes [2, 3] that are mechanically stable and relatively transparent between 12.4 nm and 16 nm.

The presented fabrication process of high-efficiency transmission masks is based on free-standing niobium membranes and demonstrate high contrast not only for in-band EUV (13.5 nm) radiation but also for wavelengths below Si L-absorption edge (12.4 nm) targeted for next-generation lithography.

The masks and filters with free standing areas up to 1000 x 1000 μm^2 and 100 nm to 300 nm membrane thicknesses are shown. Electron beam lithography and ion beam etching of an absorber layer with dense line and dot patterns with sub-50 nm structures is demonstrated [4].

Fabrication Process

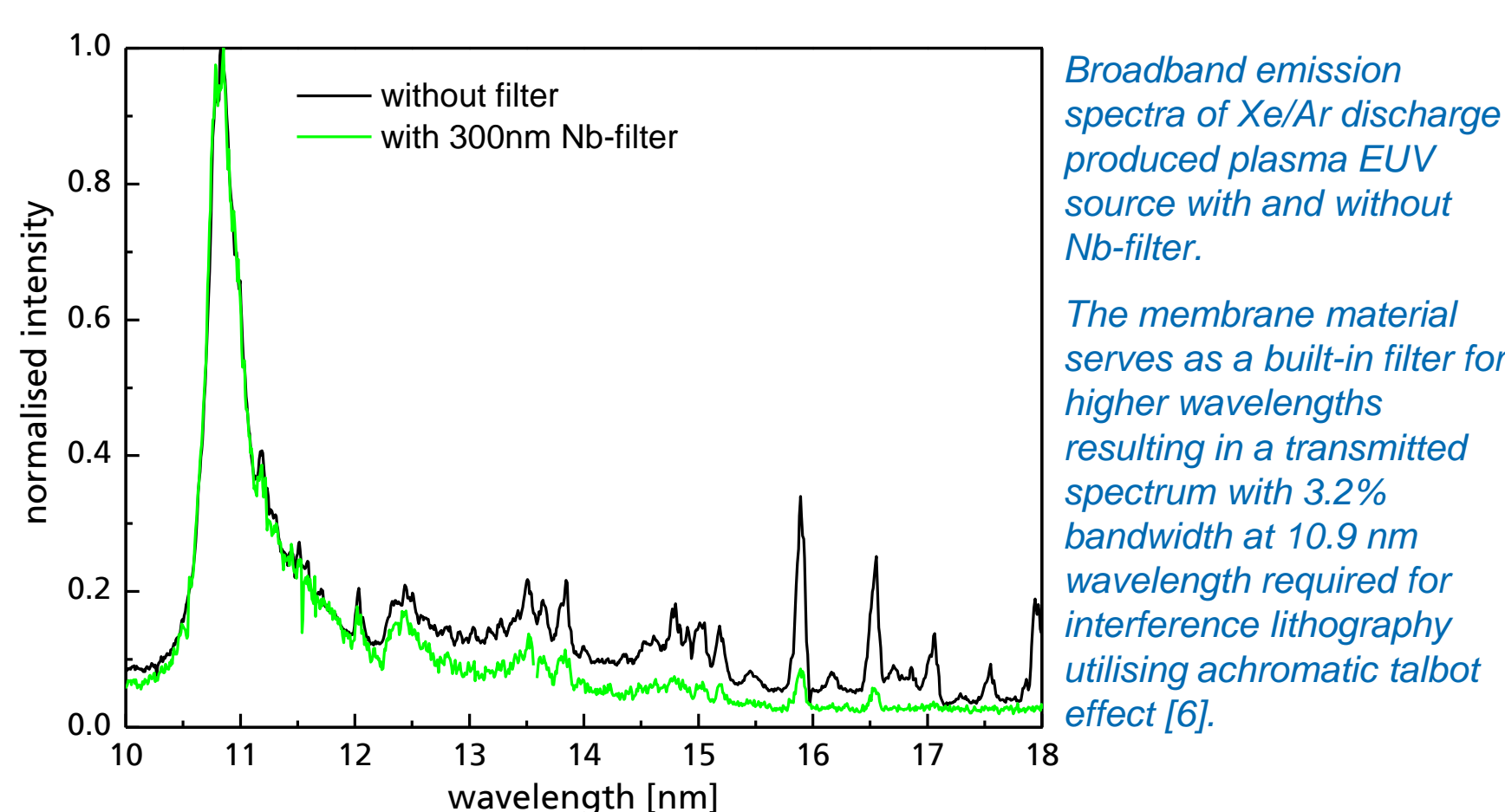
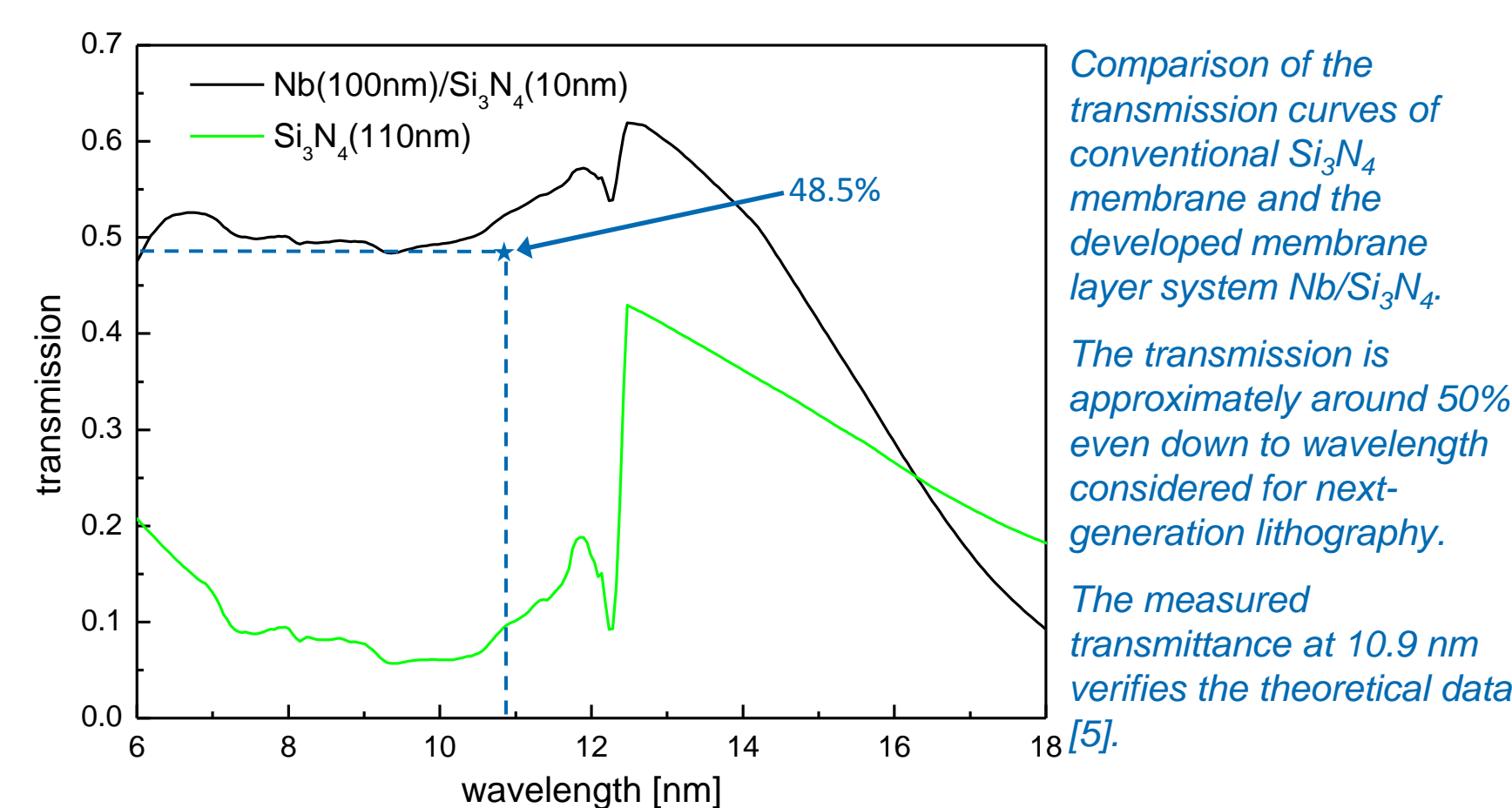


Simplified process flow of the fabrication process. In reality the process consists of more than 30 different process steps.

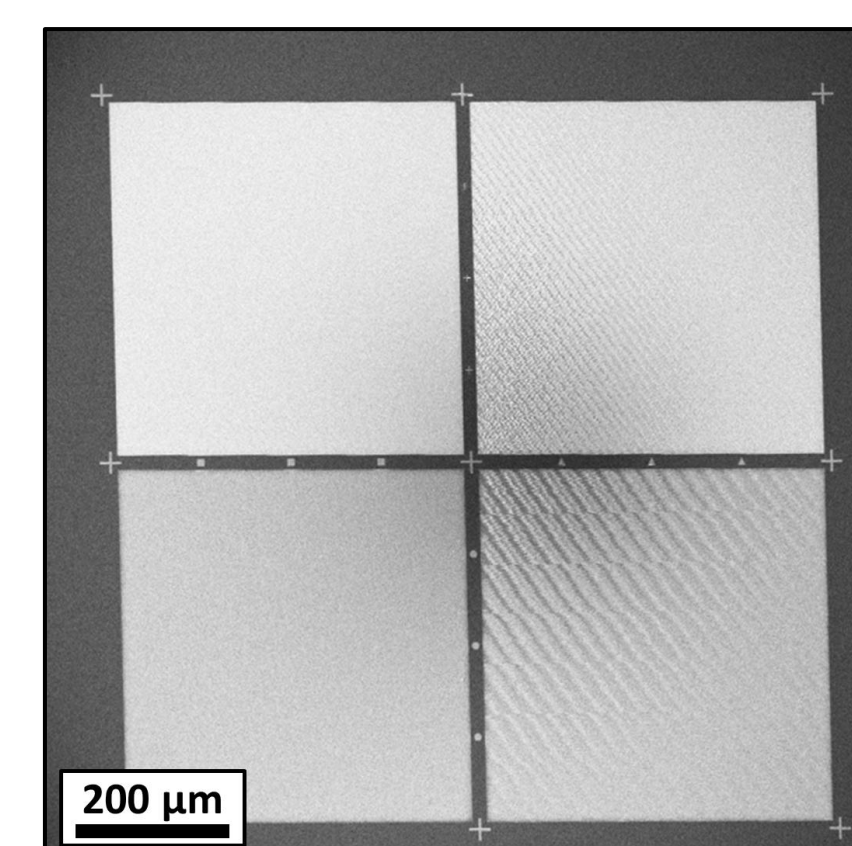
The most critical steps are shown in this scheme:

1. Deposition of high quality and homogeneity layers on chemically cleaned silicon to avoid pores and pinholes.
2. E-beam lithography of high resolution resists with preceding fine dose selection.
3. Structure transfer into absorber layer via ion beam etching.
4. Anisotropic wet etching process for silicon (100) substrate removal.

Transmission Measurements



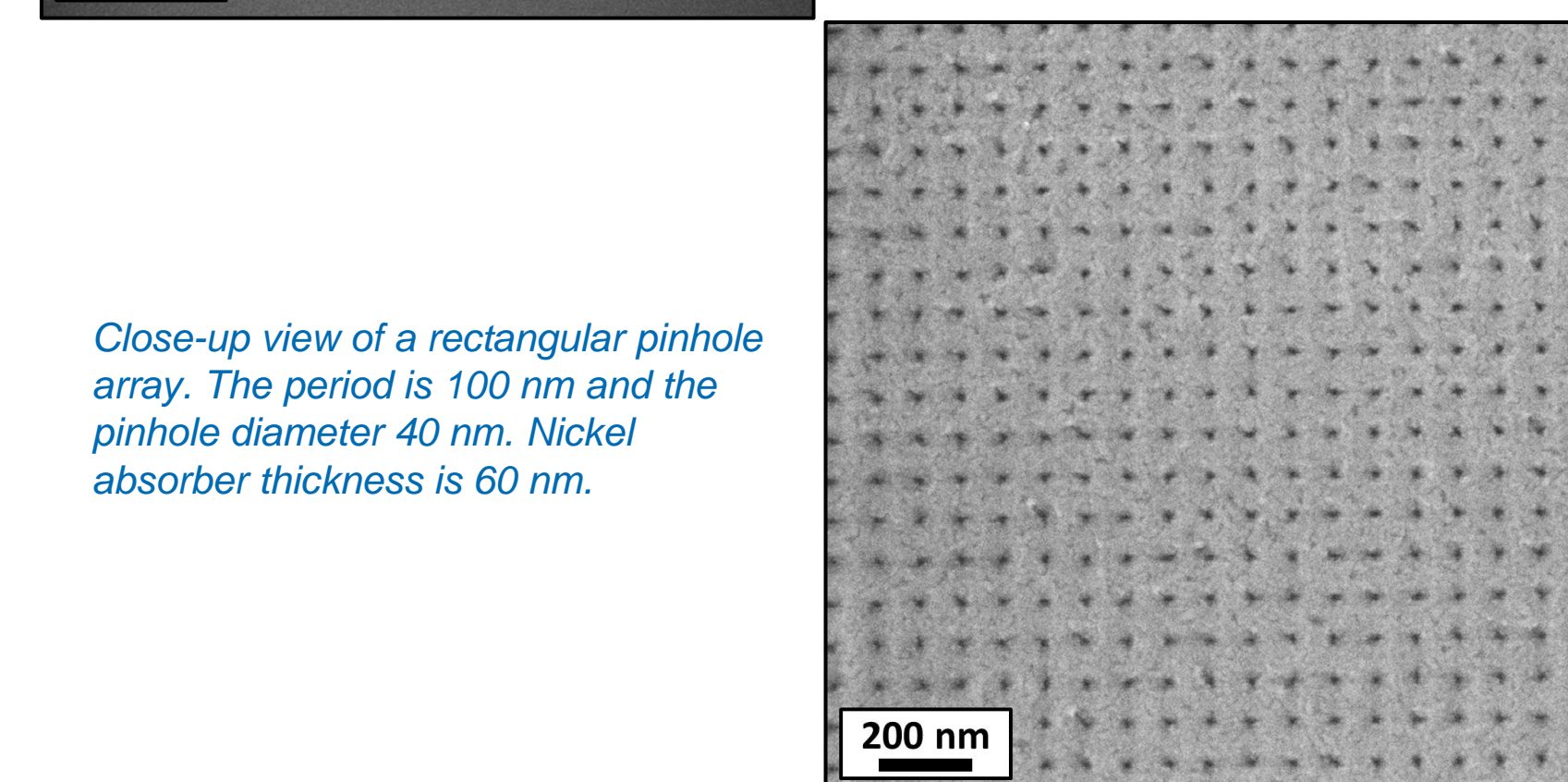
Mask Patterns



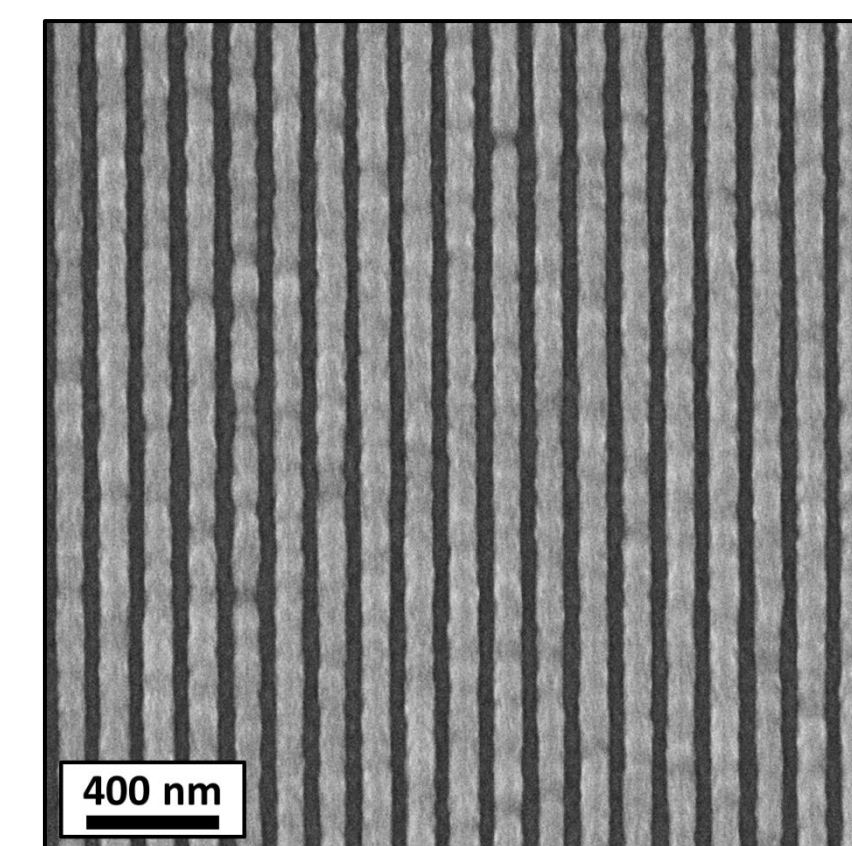
Overall mask layout. The complete main field size is in this case 1 x 1 mm².

The main field is divided into four sub fields to realize different pattern types with just one illumination step.

The mask is equipped with a set of alignment markers to allow implementation of a EUV lithography process into existing process chains.

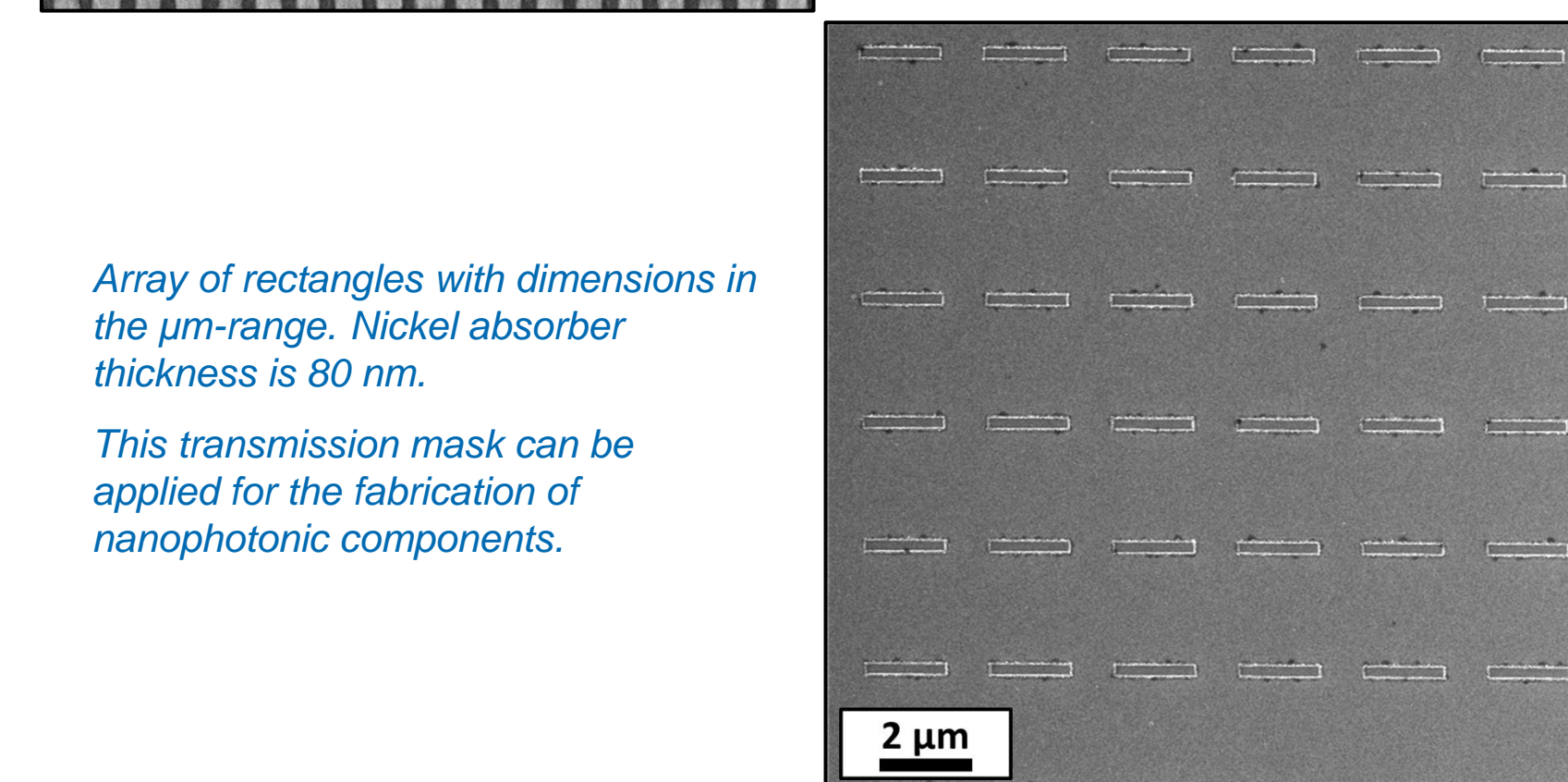


Close-up view of a rectangular pinhole array. The period is 100 nm and the pinhole diameter 40 nm. Nickel absorber thickness is 60 nm.



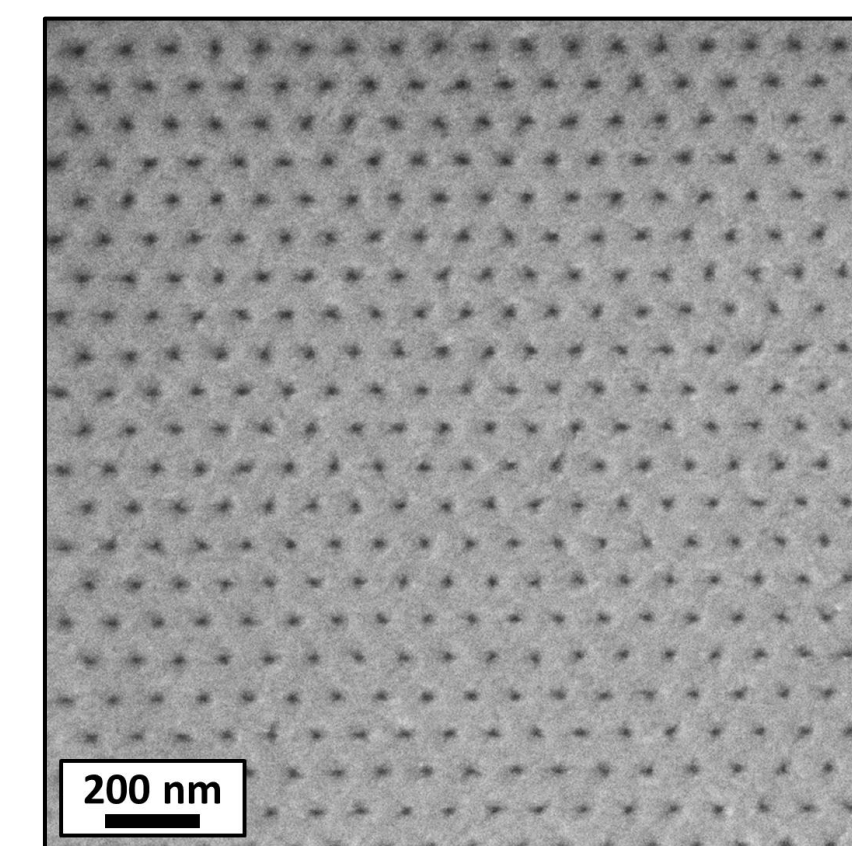
Close-up view of a lines/spaces array with a period of 150 nm, line width is approximately 90 nm. The line edge roughness is +/- 5 nm. Nickel absorber thickness is 50 nm.

The subjacent niobium membrane is clearly visible.



Array of rectangles with dimensions in the μm -range. Nickel absorber thickness is 80 nm.

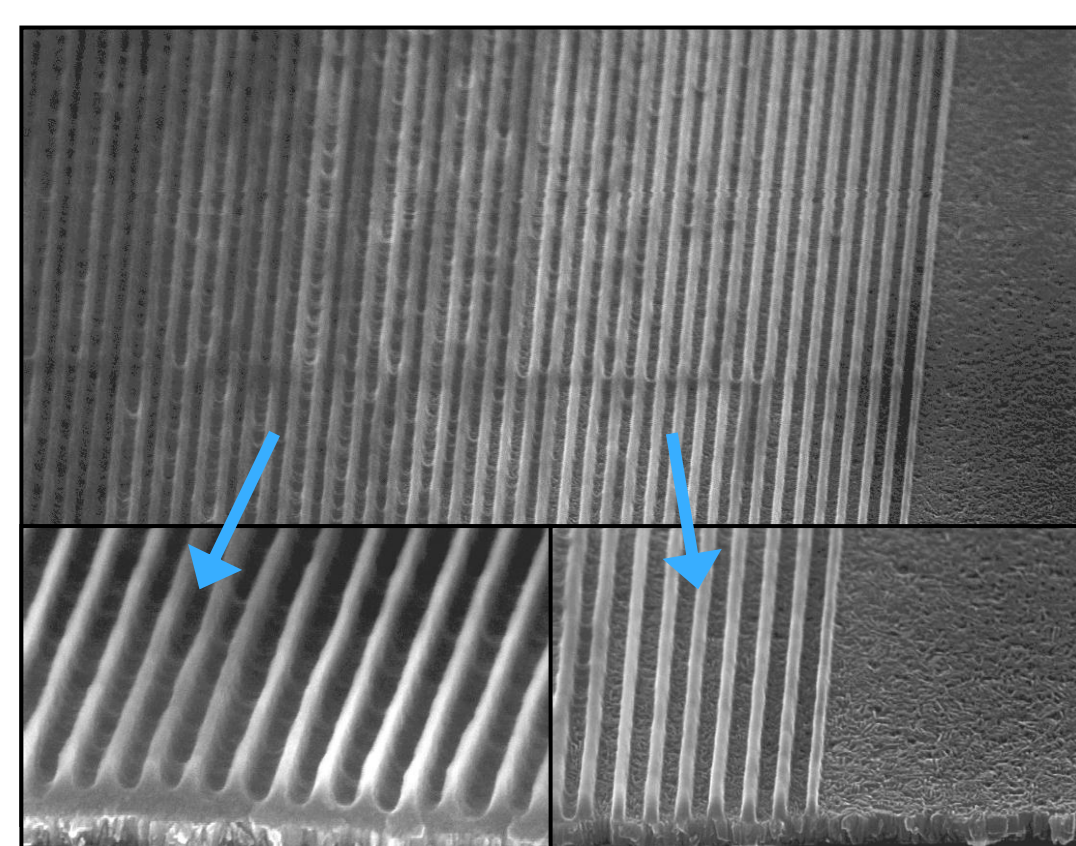
This transmission mask can be applied for the fabrication of nanophotonic components.



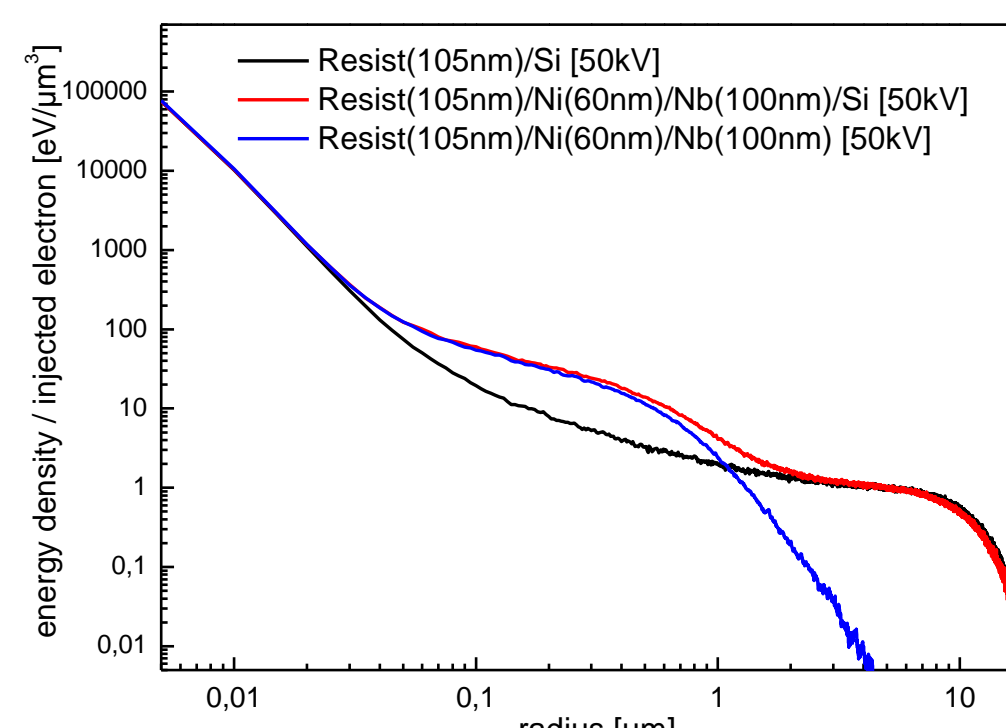
Close-up view of a hexagonal pinhole array. The period is 100 nm and the pinhole diameter 40 nm. Nickel absorber thickness is 60 nm.

Resist Patterning

- **Electron beam lithography** has to be done on Nb/Ni (increased electron backscattering)
- dense structures over large areas (fill factor ~50%)
- resist thickness of at least 60 nm is needed for structure transfer (IBE)
- > high resolution and contrast e-beam resists
- > fine dose selection
- > optimized development process



50 nm lines/spaces array in 80 nm thick HSQ negative resist. Left inset: overexposed area due to electron backscattering. Right inset: good resolved structures but only on the edge of the 500 x 500 μm^2 array.

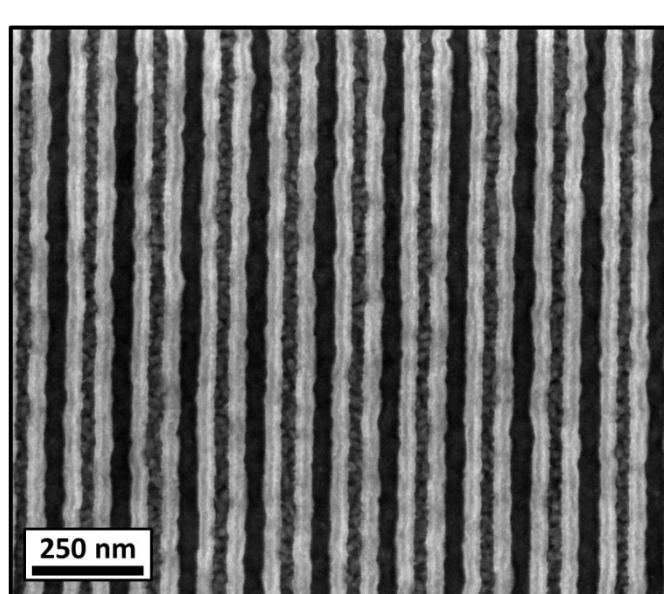


Monte Carlo[®] simulation of electron backscattering on different layer systems at 50 kV acceleration voltage.

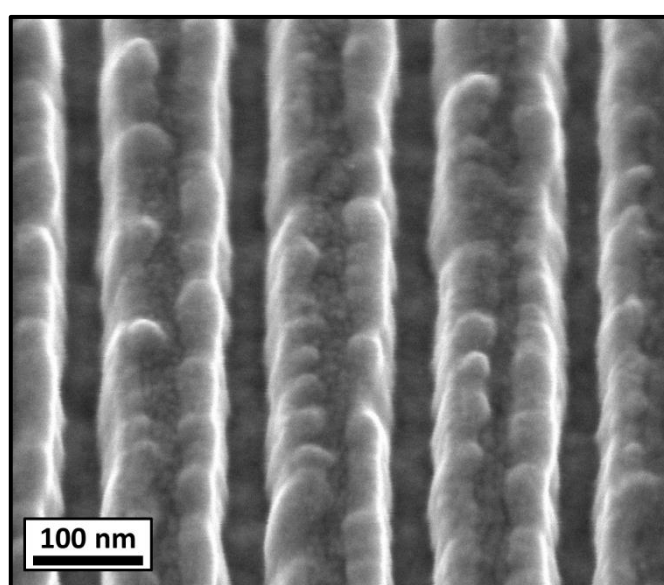
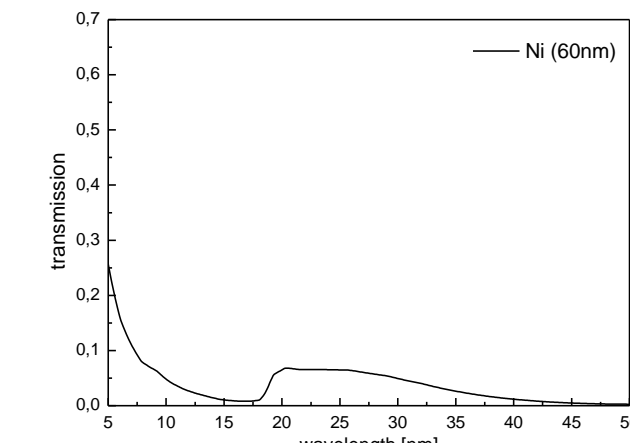
The influence of niobium and nickel is clearly visible in a range of 30 nm up to 2 μm around the injection point.

Structuring the resist directly on the membrane reduces the long range scattering introduced by the substrate.

Structure Transfer



- Nickel is one of the best absorbers at these wavelengths (3.5% transmission at 11 nm wavelength for a thickness of 60 nm).



- Nickel is structurable by **ion beam etching**.
- Nickel redeposition occurs during etching process and limits minimal structure size and period.

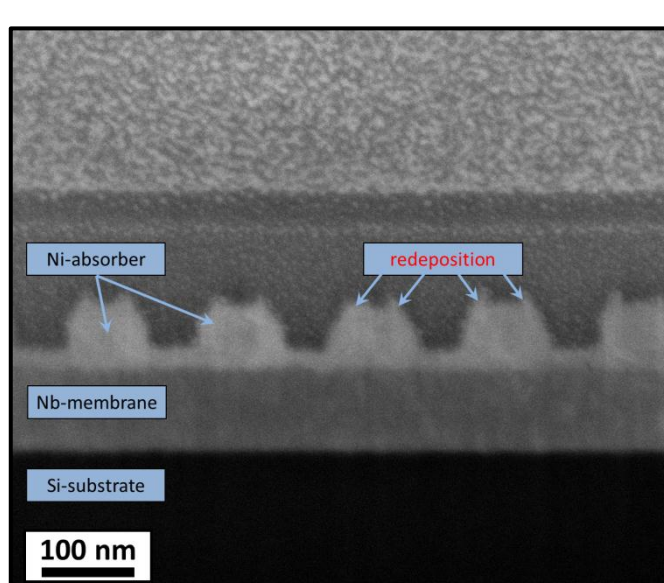
-> Optimization of IBE process:

- Etching angle
- Sample rotation
- Acceleration voltage

75 nm L/S mask with structures transferred into the nickel absorber layer.

The edges of the absorber lines show a high line edge roughness created by redeposition during the ion beam etching transfer process.

In the cross section the applied layer system is pointed out.



Outlook

Approaches for further **structure and period reduction**:

- Reduction of nickel redeposition.
- Application of selective nickel electroplating deposition (currently under investigation).
- Decreasing the absorber thickness.
- Chrome absorber layer instead of nickel enables implementation of highly selective RIE Cl_2 -process.
- Instead of creating amplitude transmission masks it is also possible to create phase shift masks based on niobium with RIE SF_6 -process.

Increase of membrane field for higher throughput:

- Optimization of internal stress distribution in niobium membrane.
- Increasing the membrane thickness leads to a stiffer membrane.
- Implementation of a support mesh into the fabrication process.
- Creation of a multi field transmission mask with silicon support structures.

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